Effects of Different Braze Materials and Composite Substrates on Composite/Ti Joints

G.N. Morscher, M. Singh, R. Asthana, and T. Shpargel

An ever increasing number of applications require robust joining technologies of dissimilar materials. In this study, three types of ceramic composites (C-C, C-SiC, and SiC-SiC) were vacuum brazed to commercially pure Ti using the Cusil-ABA (63 Ag – 35.5 Cu – 1.75 Ti) active metal braze alloy. The study also compared composite specimens as-fabricated and after surface grinding/polishing. A butt-strap tensile shear strength test was used to evaluate the joined structures at room temperature, 270 and 500 ^{o}C. The elevated temperatures represent possible use temperatures for some heat rejection type applications. Joint strength will be discussed in light of braze wetting and spreading properties, composite properties, and test temperature.

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Gregory N. Morscher and Mrityunjay Singh
Ohio Aerospace Institute; NASA Glenn Research Center
Cleveland, OH

Rajiv Asthana
University of Wisconsin at Stout

Tarah Shpargel
ASRC Aerospace, NASA Glenn Research Center
Cleveland, OH

Background

- Application: Heat rejection systems requiring C/C facesheets joined to Ti tubes (Prometheus Program)
  - Temperatures range from -100 to 300°C

- Issues:
  - Thermal expansion mismatch between C/C ($-1x10^{-6}/^{o}C$) and Ti ($8.6x10^{-6}/^{o}C$) and high braze temperature (up to 1000°C)
  - Wetting, spreading and bonding of braze to composite substrate
  - Inherent interlaminar weakness of composite substrate
  - Effective tests to evaluate joints

Our Approach

- Select baseline C/C composite and determine effect of different brazes and a solder on joining C/C to Ti
  - Tube tests and butt-strap tensile shear tests
- Use “best” braze from and compare shear strength of C/C substrate joints to C/SiC and SiC/SiC
  - Butt-strap tensile shear tests
- Investigate use of HT-POCO foam as saddle material to alleviate thermal strain between C/C and Ti
  - Ti Tube-POCO-C/C multilayer structures → tensile and shear tests

Effect of Braze on C/C to Ti Joints

Experimental: Materials

- Grade 2 Ti tubes and plates – TIMET Inc., MO
- Woven P120 carbon fiber, chemical vapor infiltrated (CVI) carbon matrix composites (1.2 mm thick) – Goodrich Corp., Santa Fe Springs, CA

Braze/Solder	**Composition**	**Liquidus Temp., °C**
TiCuSil Braze*	68.8 Ag, 26.7 Cu, 4.5 Ti	900
CuSil ABA Braze*	63.0 Ag, 35.3 Cu, 1.8 Ti	815
CuSin-1 ABA Braze*	63.0 Ag, 34.3 Cu, 1.8 Ti, 1.0 Sn	806
Incusil ABA Braze*	59.0 Ag, 27.3 Cu, 1.3 Ti, 12.5 In	715
S-Bond 400 Alloy Solder#	Zn, Ag, Al, with trace amounts of Ga and Ce	410 - 430

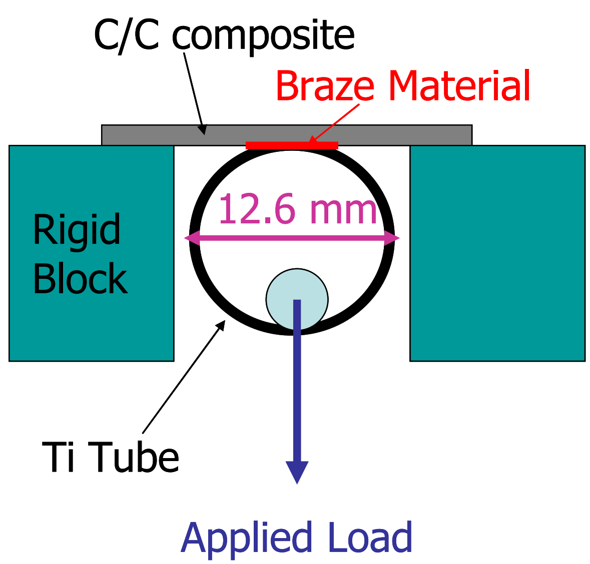
* Morgan Advanced Ceramics, CA
\# S-Bond Technologies, PA

Earlier study evaluated higher temperature brazes (Cu-ABA; TiCuNi; TiCuSil) and lower conductivity C/C; *Mater. Sci. Eng. A.*, 418, 19-24 (2006)

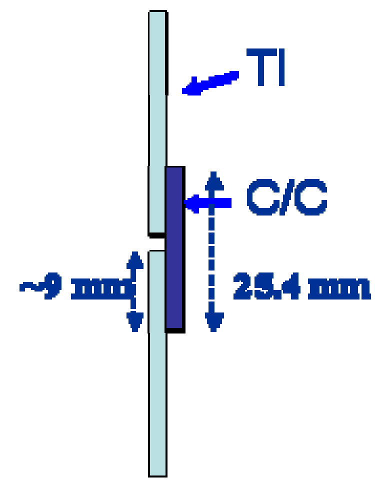
Experimental: Test Techniques and Specimens

Factors considered:

- Effectiveness of braze bonding → FAILURE LOCATION
- Degree of braze spreading → BONDED AREA
- Evidence of thermally induced CRACKING



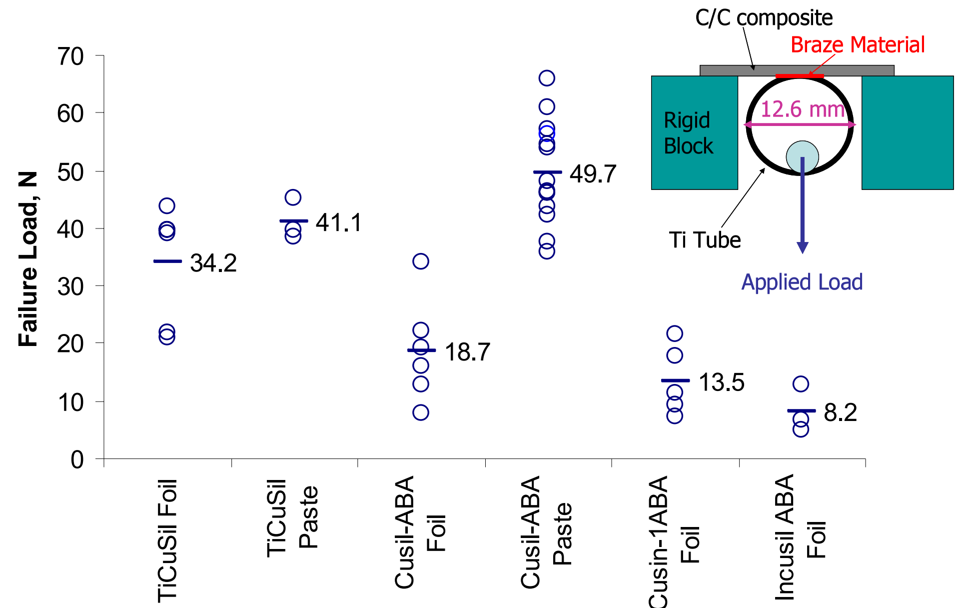
Tube-Plate Tensile Test

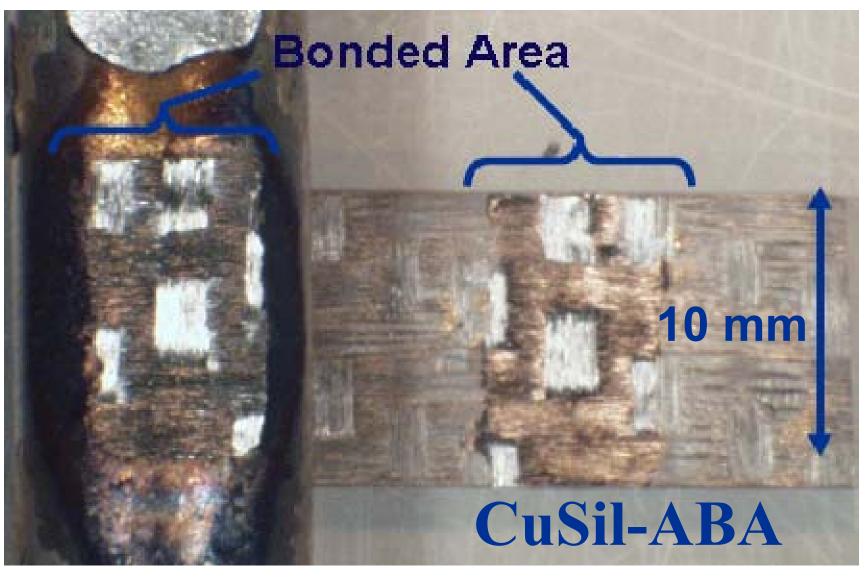


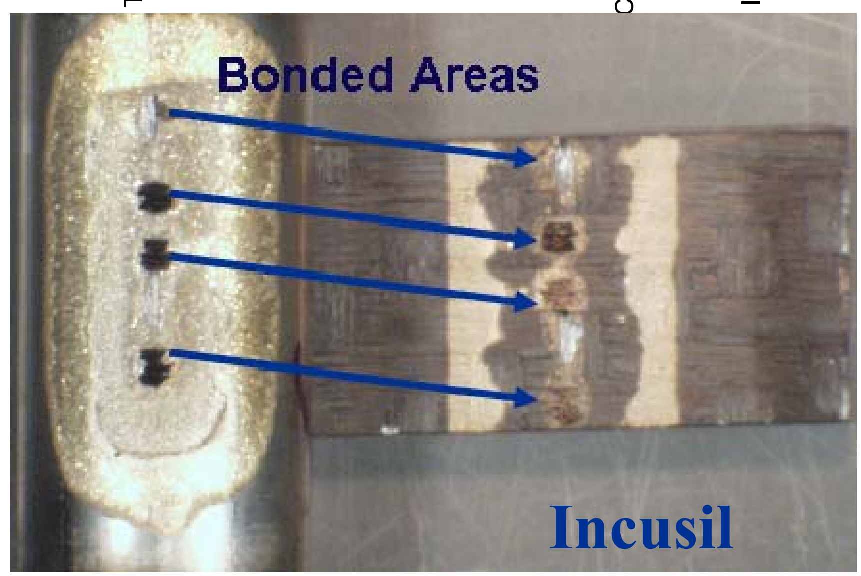
Butt-Strap Tensile (BST) Shear Test

Tube-Plate Tensile Test

- Cusil-ABA, followed by TiCuSil, had highest load-carrying ability and largest bonded area
- Cusin-1ABA and Incusil ABA had lowest load-carrying ability and poor braze spreading
- Tensile "Strength" approx. 0.5 MPa
- P120 C/C (CVI) brazed to Ti is stronger than T300 C/C (resin-derived) brazed to Ti (TiCuSil Foil load ~ 9 N) of earlier study

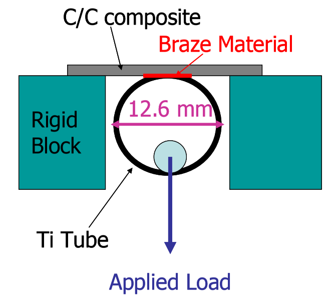


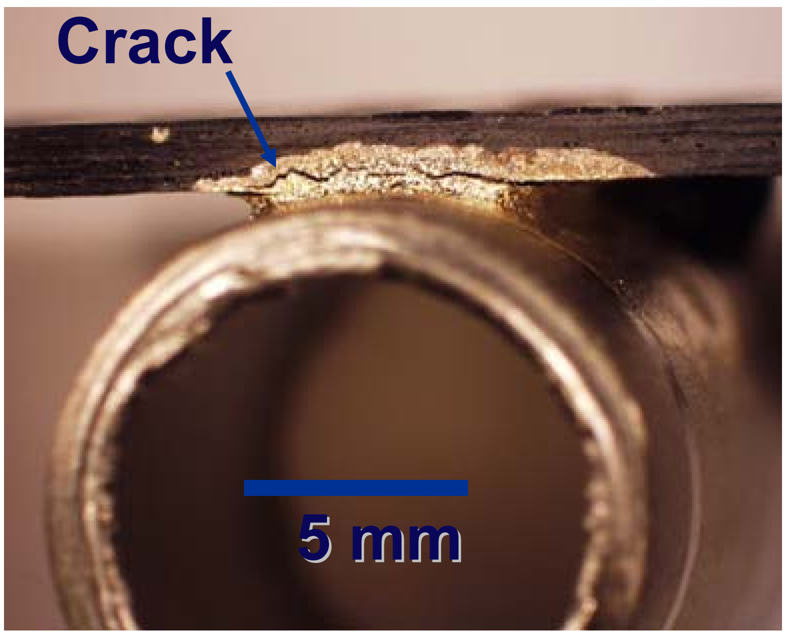


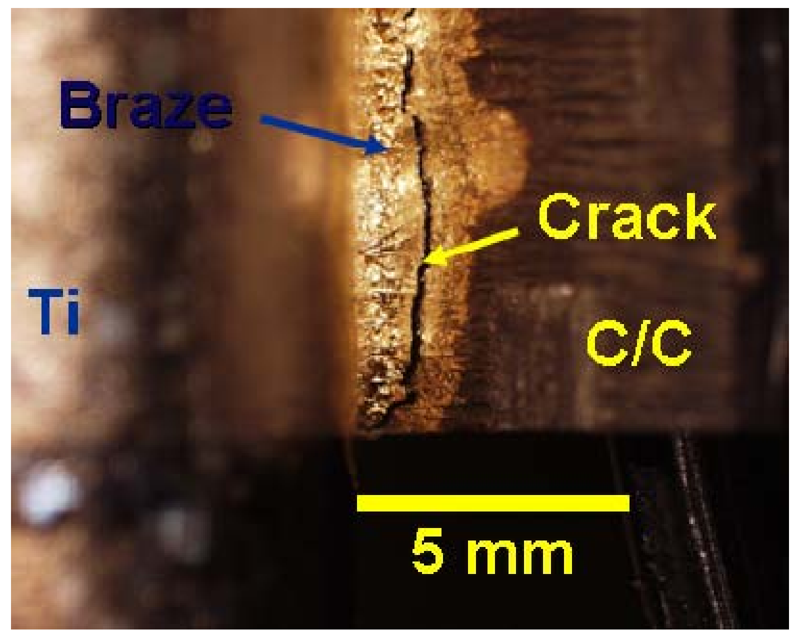


Tube-Plate Tensile Test → $\Delta\alpha\Delta T$ Cracks

- All brazes showed evidence of pre-existing cracks in the braze and outer ply of C/C



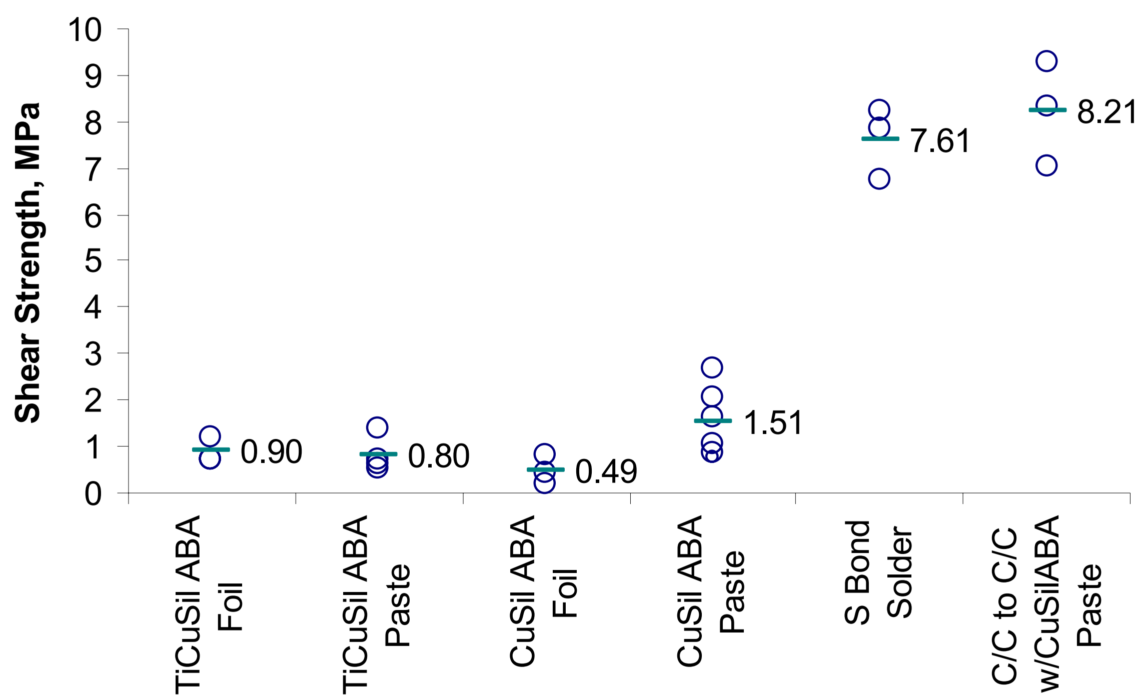


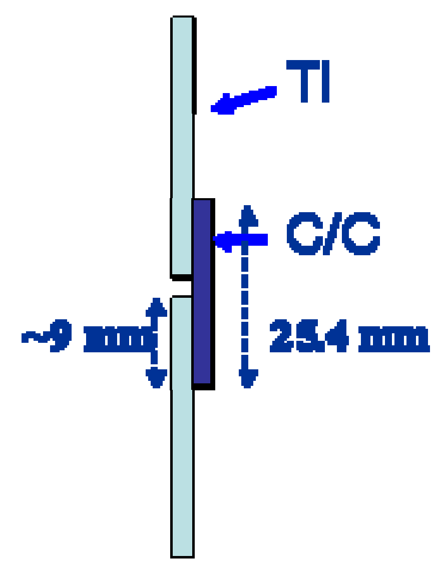


TiCuSil paste as-fabricated

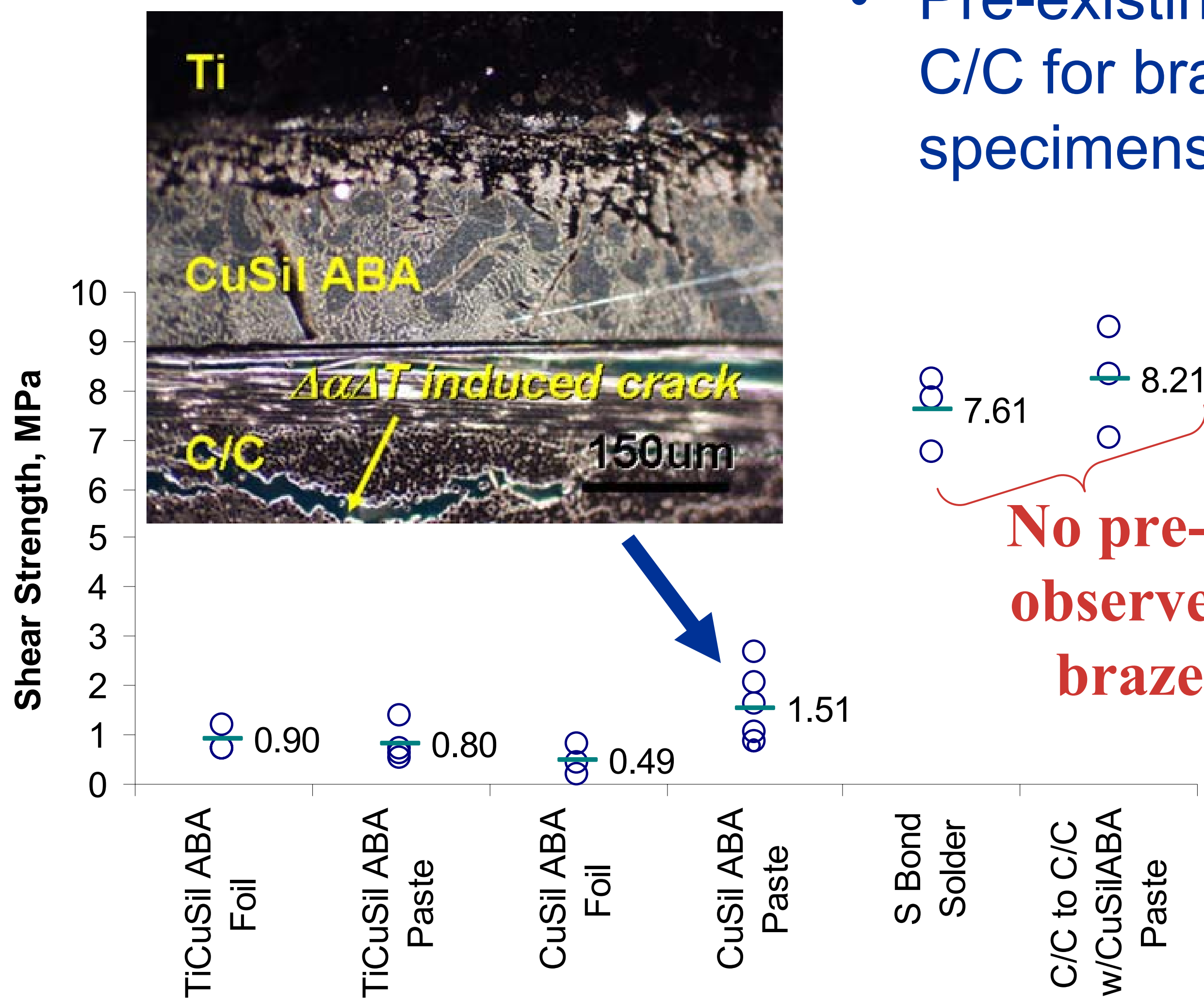
Butt-Strap Tensile Shear Test

- Solder resulted in significantly higher shear strengths than brazes for Ti to C/C
- C/C brazed to C/C exhibited high shear strength as well





Butt-Strap Tensile Shear Test

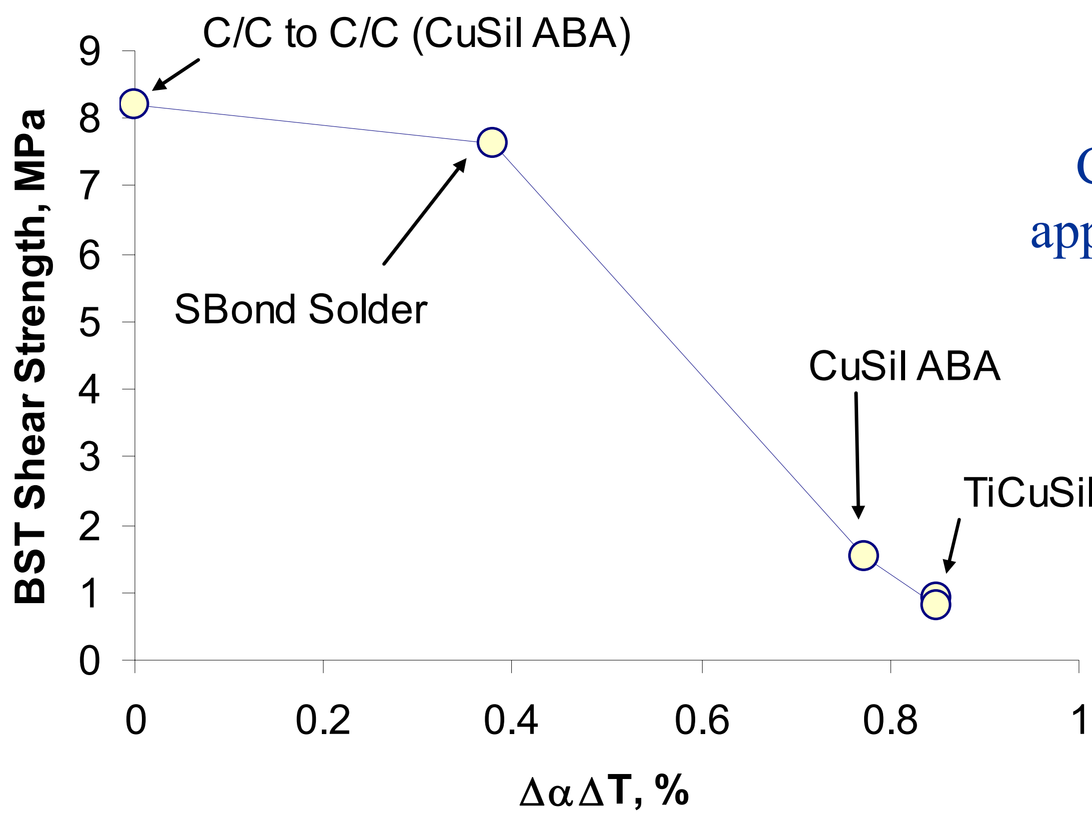


- Pre-existing cracks in C/C for brazed specimens due to $\Delta\alpha\Delta T$

No pre-existing cracks observed in S Bond or brazed C/C to C/C

Effect of $\Delta\alpha\Delta T$ (Estimated) on Shear Strength

- Assumes elastic behavior, CTE(Ti) = 8.6×10^{-6}/C; CTE (C/C) = -1×10^{-6}/C
- Only brazes and solder which showed full spreading were compared



C/C shear strength approximately 15 MPa

CuSil ABA selected as "best braze" because solder melting temperature (~ 410C) too low compared to application temperature (~ 300C)

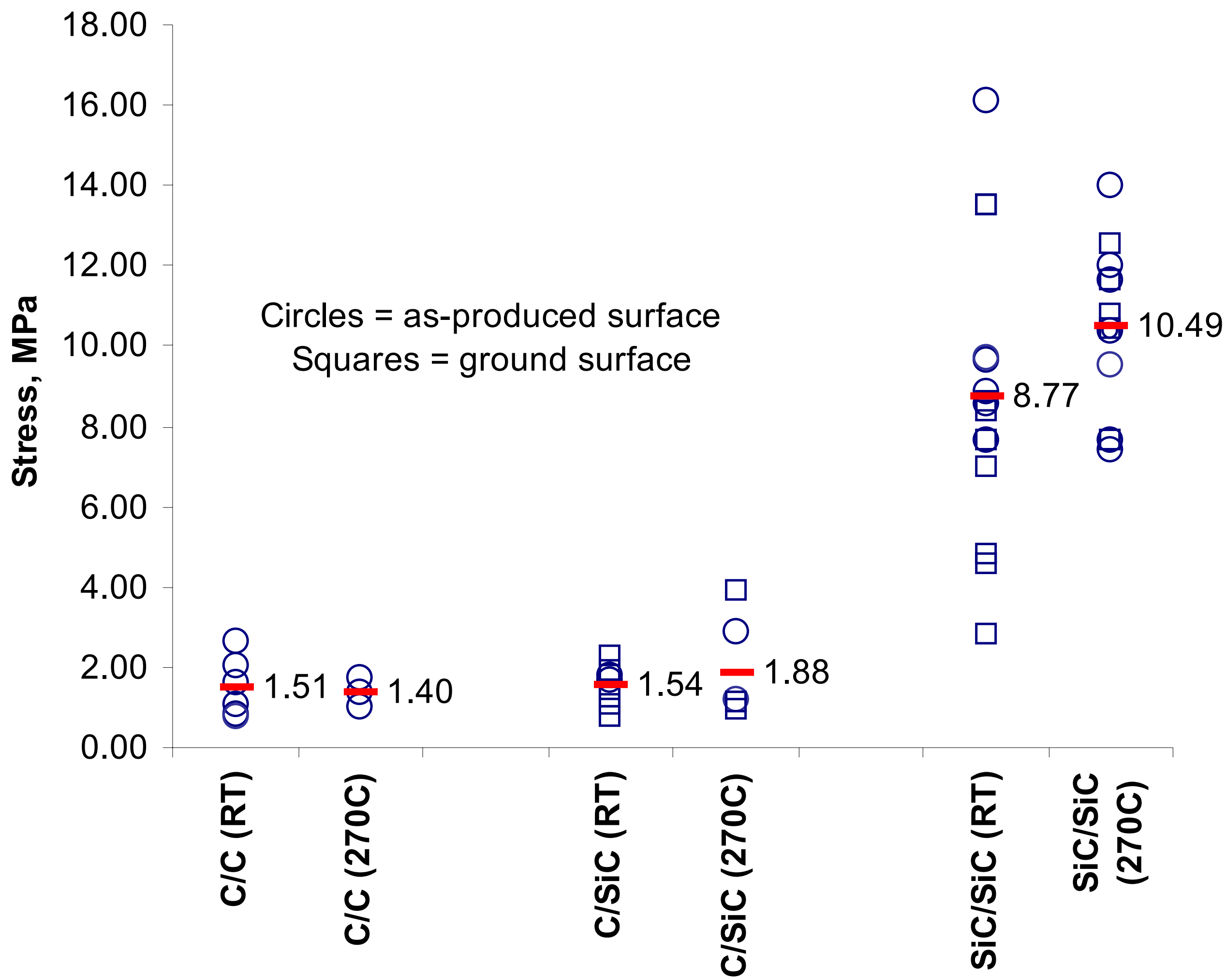
Effect of Composite Substrate When Using CuSil-ABA Paste as Braze (for other applications)

Butt-Strap Tensile Shear Tests

C/SiC = T300 reinforced CVI SiC

SiC/SiC = Sylramic reinforced Melt-Infiltrated SiC

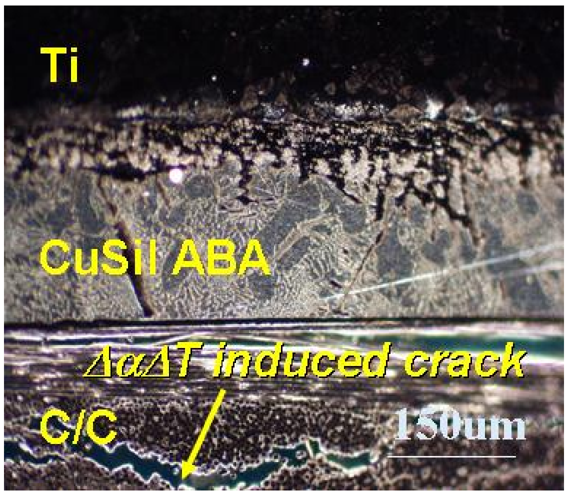
BST Shear Stress at Room and 270°C



No difference in average values for as-produced and ground surfaces

Thermally-Induced Cracking in Composite Controls Shear Strength of Brazed Joints

$\tau_{xy} \cong 1.5$ MPa



Ti-C/C Composite

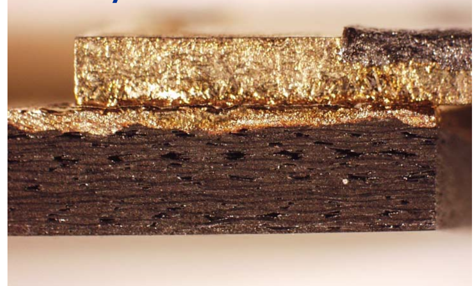
Interlaminar shear strength

C/C $\cong$ 10-15 MPa

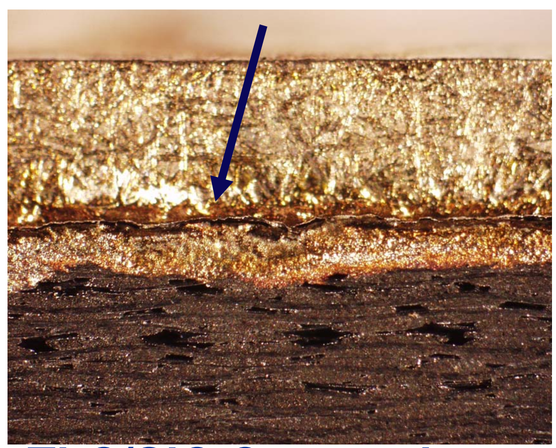
C/SiC $\cong$ 15-25 MPa

SiC/SiC $\cong$ 35-45 MPa

$\tau_{xy} \cong 1.7$ MPa

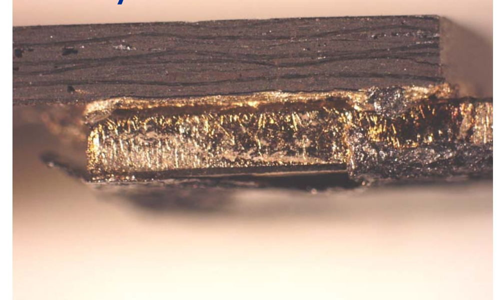


Crack in outer ply of C/SiC

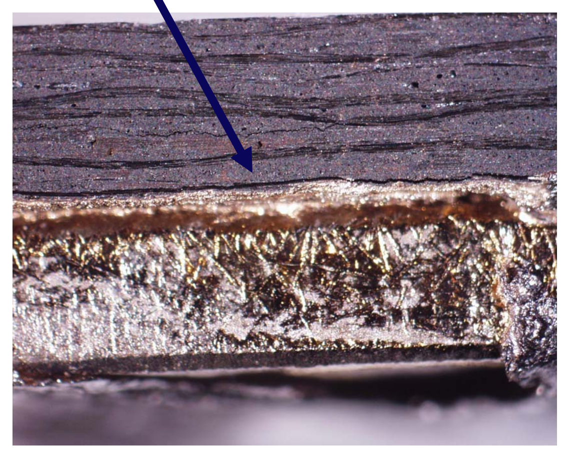


Ti-C/SiC Composite

$\tau_{xy} \cong 10$ MPa



Crack in outer ply of SiC/SiC

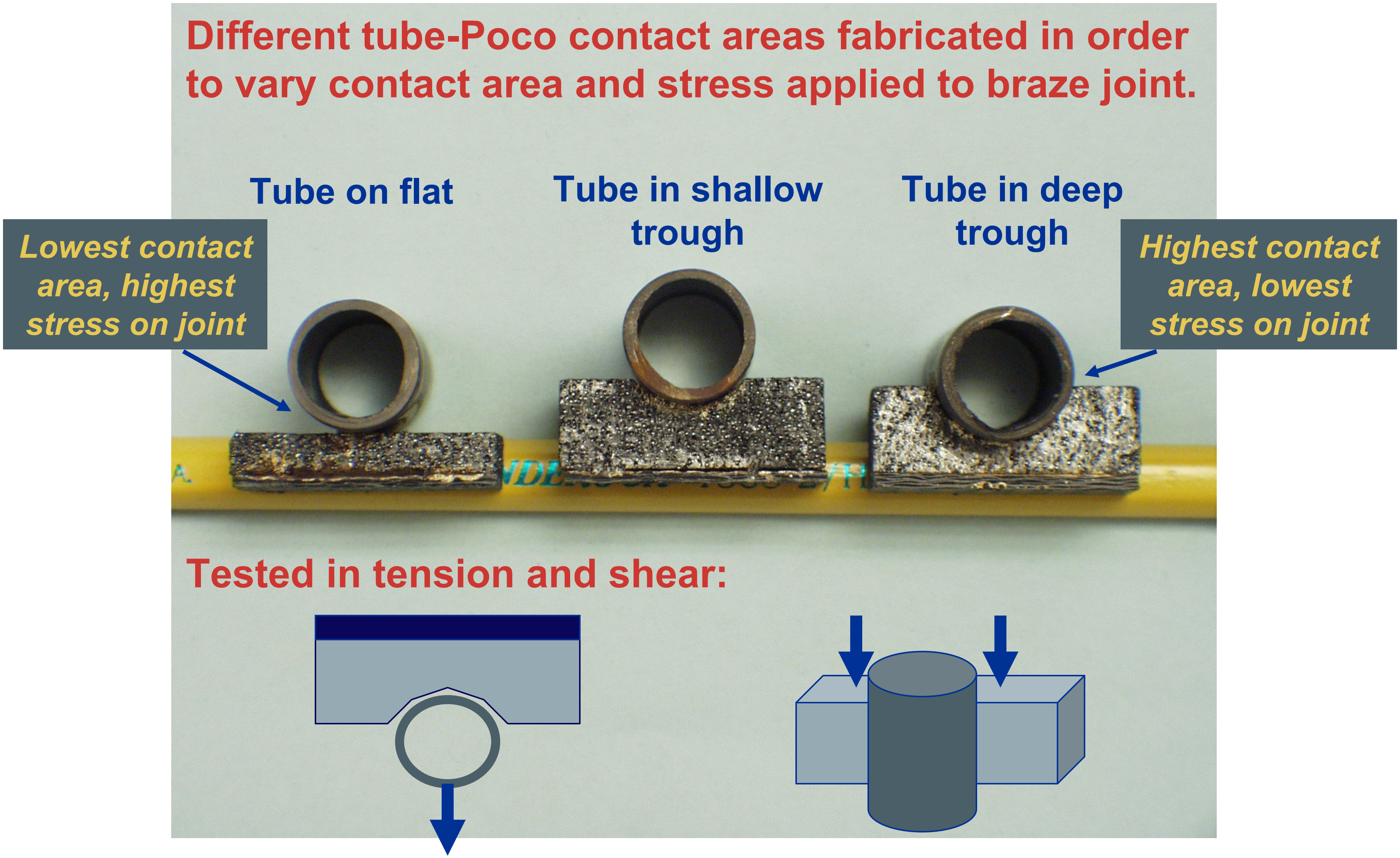


Ti-SiC/SiC Composite

Use of HTPOCO Foam as Saddle Material: C/C – HTPCO – Ti tube Multilayer Structures

Cu-Sil ABA paste used to braze each joint

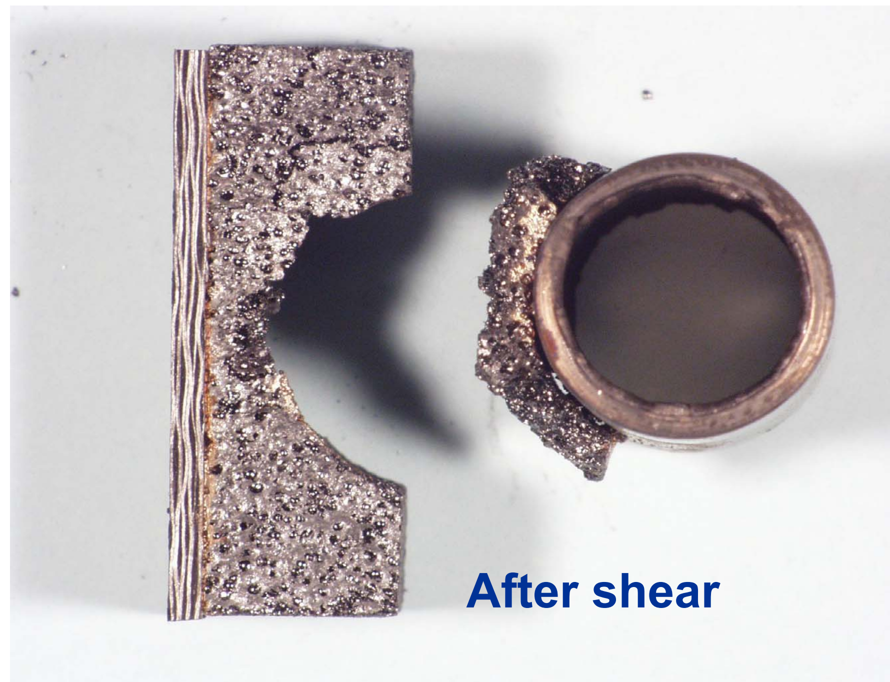
Poco Foam Structures with C/C Facesheet



Poco Foam Sandwich Structures with Woven K1100 and/or Woven P120 C/C Facesheet

- **EXCELLENT ADHESION OF BRAZE TO FOAM AND Ti TUBE. FAILURE ALWAYS OCCURRED IN POCO.**

Maximum *tensile stresses* subjected to braze *exceeded 7 MPa* based on load applied and approximate braze area.



Maximum *shear stresses* subjected to braze *exceeded 12 MPa* based on load applied and approximate braze area.

Conclusions

- C/C composites could be brazed to Ti plates or tubes, the paste form of Cusil-ABA providing the best performance of the braze materials studied here
- Braze/Solder bonding & spreading to C/C and processing temperature (thermally-induced strain) are strongest factors controlling joint strength
  - S Bond solder outperformed all brazes due to lower processing temperature – cracks were formed in braze and C/C for all of the brazed joint specimens, but were not formed in the S Bond solder specimen
  - Cusil-ABA (paste form) outperformed all brazes because it was the lowest processing temperature braze of all the brazes which fully spread and bonded to C/C
- The higher conductivity P120 CVI C/C appears to enable stronger joints compared to the T300 Resin-Derived C/C tested in the earlier study
- SiC/SiC composites had higher joint strengths than C/C or C/SiC, presumably because the interlaminar shear strength of SiC/SiC is greater than the other composites
- The Poco Foam is the weak link in the tube-foam structures and not the brazed joint. Failure in tension and shear always occurs in the foam whether or not the Ti tube was brazed to a curved Poco surface to maximize bond area or a flat Poco surface to maximize stress in the joint.